UNITED STATES PATENT APPLICATION

for

LAYOUT AND PROCESS FOR A DEVICE WITH SEGMENTED BALL LIMITING METALLURGY FOR THE INPUTS AND OUTPUTS

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BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to the field of semiconductor Integrated Circuits (IC), and more specifically, to a layout and process for a device with segmented Ball Limiting Metallurgy (BLM) for the Inputs/Outputs (I/Os).

2. DISCUSSION OF RELATED ART

I/Os are used in a device to condition and distribute power, ground, and signals. The I/Os can be wirebonded to a package or board with leads formed from Gold (Au) or Copper (Cu) wire. However, when the number of I/Os reaches about 400 to 1000, bumping often becomes more advantageous than wirebonding.

Figure 1 (a) and **Figure 1 (b)** show a solder bump **15** with a diameter **1** and a pitch **2.** The solder bump **15** is formed on Ball Limiting Metallurgy (BLM) **14.** BLM is also known as Pad Limiting Metallurgy (PLM) or Under Bump Metallurgy (UBM). The BLM **14** is connected through a via **12** in the passivation layer **13** to an underlying bond pad **11b**. The passivation layer **13**, comprises one or more layers of materials, such as silicon oxide, silicon nitride, or polyimide, which act as a barrier to moisture, ions, or contaminants. The bond pad **11b** is a widened portion of a metal line **11a** in the top metal layer of the device. The line **11a** is connected to an underlying via **10** that is, in turn, connected to an underlying line **9.** A device typically has 2 to 8 metal layers so a via and a line are alternated vertically until electrical contact is made to the desired part of the IC or the substrate below.

Bumping can significantly improve access to the [redacted] area and maximize utilization of the silicon area. **Figure 1 (a)** and **Figure 1 (b)** show an areal array **3** of bumps **15** across the entire active area of the chip. The array **3** is substantially periodic and may be face-centered cubic or hexagonal to achieve a higher density of bumps **15**. A bumped device is turned over and packaged as a Flip Chip (FC). A solder bump technology based on Controlled Collapse Chip Connection (C4) may be used for Direct Chip Attach (DCA) to conductive traces on a package or circuit board. The circuit board may be a ceramic substrate, Printed Wiring Board (PWB), flexible circuit, or a silicon substrate. Bumping a device also reduces the resistance and inductance in the I/Os thus significantly improving performance.

A high performance device, such as a microprocessor, an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), or a System-on-a-Chip (SOC), may have about 600 to 7000 I/Os so the I/Os need to be scaled down to limit die size. Wirebonding may involve a pitch of less than 60 microns using wires with a diameter of less than 25 microns with ball bonds of less than 40 microns. Bumping may involve bumps with a diameter of about 45 to 90 microns and a pitch of about 125 to 300 microns.

Power management and thermal management become very critical when wire leads or bumps are scaled down. I/Os may fail if junction temperature exceeds 100 to 125 degrees C or current density exceeds 150 to 425 milliamperes per I/O. Electromigration or thermomigration can increase resistance by over 2 orders of magnitude before finally resulting in an open circuit. Elevated temperatures can also cause inter-diffusion of metals. The resultant intermetallic alloys are brittle and may be susceptible to stress cracking. A mismatch in the Coefficient of Thermal Expansion (CTE) can result in large shear stresses on a wire lead or bump. For example, solder has a CTE of about 30 ppm/degree C compared with about 7 ppm/degree C for a ceramic substrate and about 5 ppm/degree C for a Silicon substrate. A wire lead or bump may fail from thermal shock if the thermal ramp rate exceeds about 15 to 20 degrees C/minute. Thermal cycling at lower thermal ramp rates may also cause a wire lead or bump to crack due to fatigue induced by elastic deformation or creep deformation.

Thus, the failure of I/Os, especially the power I/Os due to high currents and high temperatures is a major concern.

Thus, what is needed is a novel layout and process for a device with segmented Ball Limiting Metallurgy (BLM) for the I/Os.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements and in which :

Figure 1 (a) is an illustration of a plane view of a bump (prior art).

Figure 1 (b) is an illustration of a cross-sectional view of a bump (prior art).

Figure 2 (a) is an illustration of a plane view of a bump connected to a BLM with two segments.

Figure 2 (b) is an illustration of a cross-sectional view of a bump connected to a BLM with two segments.

Figure 3 is an illustration of a plane view of a bump connected to a BLM with four segments.

Figure 4 is an illustration of a plane view of a bump connected to a BLM with two segments where each segment is connected to two vias.

Figure 5 is an illustration of a plane view of a bump connected to a BLM with two segments where each segment is connected to two bond pads.

Figure 6 (a) – (f) are illustrations of an embodiment of a process for forming segmented BLM.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

The present invention discloses a novel layout and process for a device with segmented Ball Limiting Metallurgy (BLM) for the Inputs/Outputs (I/Os). The invention further discloses that a segment of a BLM may be electrically connected to more than one underlying via or bond pad. The invention can reduce the incidence and minimize the severity of I/O failure due to operation at high current and high temperature.

In the following description, numerous details, such as specific materials, dimensions, and processes, are set forth in order to provide a thorough understanding of the present invention. However, one skilled in the art will realize that the invention may be practiced without these particular details. In other instances, well-known semiconductor equipment and processes have not been described in particular detail so as to avoid unnecessarily obscuring the present invention.

The layout of the device in the present invention will be described first.

According to a first embodiment of the present invention, a BLM is split into two segments **24n** as shown in **Figure 2 (a)** and **Figure 2 (b)**. One or more of the segments **24n** may have a substantially polygonal layout, such as a hexagon or an octagon. The segments **24n** are in close proximity to each other. The gap **23** between the segments **24n** will block the propagation of a defect arising in any individual segment **24n.** The segments **24n** also provide redundancy to counteract defects that may occur randomly in the segments **24n**.

Both segments **24n** are connected to the same overlying bump **25** as shown in **Figure 2 (a)** and **Figure 2 (b)**. Each segment **24n** is also connected to one underlying via **22n**. One or more of the vias **22n** may have a substantially polygonal layout, such as a square or a rectangle. The vias **22n** are in close proximity to each other. The spacing **26** between the vias **22n** will block the propagation of a defect arising in any individual via **22n**. The vias **22n** also provide redundancy to counteract defects that may occur randomly in the vias **22n**. One or more of the vias **22n** may be laterally offset **27** from the overlying

bump **25** to which they are electrically connected. Both **22n** are connected to the same underlying bond pad **21b**. The bond pad **21b** is a portion of the underlying line **21a** that has been widened to ensure that the via **22n** will make full contact with the line **21a** despite any misalignment.

According to a second embodiment of the present invention, a BLM may be split into more than two segments, such as the four segments **34n** shown in **Figure 3**. All four segments **34n** are connected to the same overlying bump **35**. Each segment **34n** is connected to an underlying via **32n**. All four vias **32n** are connected to the same underlying line **31a** at the bond pad **31b**.

According to a third embodiment of the present invention, each segment **44n** of a BLM may be connected to more than one via **42n**, such as the two vias **42n** shown in **Figure 4**.

According to a fourth embodiment of the present invention, each segment **54n** of a BLM may be connected to more than one bond pad **51b**, such as the two bond pads **51b** shown in **Figure 5**.

The process to form the segmented BLM of the present invention will be described next.

First, the passivation layer **23** is patterned to form vias **22n** to expose the bond pad **21b** as shown in **Figure 6 (a)**. The patterning can be done with photoresist or with photodefinable polyimide.

Next, BLM is formed, usually by sputtering. The BLM usually has a lower layer **24a** and an upper layer **24b** as shown in **Figure 6 (b)**. The lower layer **24a** provides good adhesion to the landing pad **21b** and the passivation layer **23.** The lower layer **24a** may be formed from Titanium (Ti) with a thickness of about 200 to 1500 Angstroms. Other possible metals for the lower layer **24a** include Titanium-Tungsten (TiW), Tantalum (Ta), Chromium-Copper (Cr-Cu), or Chromium (Cr). The upper layer **24b** provides good adhesion to the lower layer **24a** and is wettable by solder. The upper layer **24b** may be formed from Nickel-Vanadium (Ni-V) with a thickness of about 1000 to 8000 Angstroms. Other possible metals for the upper layer **24b** include Nickel (Ni), Chromium-Copper (Cr-Cu), Copper (Cu), Gold (Au), Nickel-Gold (Ni-Au), or Copper-Gold (Cu-Au).

The lower lay[redacted]4a and the upper layer **24b** of the [redacted]M act as diffusion barriers to metals. However, depending on the type of metallurgy selected for the bump **25** and the BLM, additional layers may be inserted between the lower layer **24a** and the upper layer **24b** to further prevent interdiffusion of metals. Any intermediate layer used must have good adhesion to both the lower layer **24a** and the upper layer **24b**. Depending on the metals used in the upper layer **24b**, a capping layer, such as Copper (Cu) or Gold (Au), may also be used over the upper layer **24b** to prevent oxidation or corrosion of the upper layer **24b**.

Photoresist is applied and patterned so a gap **23** can be etched in the BLM between the vias **22n** as shown in **Figure 6 (c)**. After stripping the photoresist, another layer of photoresist is applied and patterned so solder **25** can be electroplated onto the BLM as shown in **Figure 6 (d)**. The solder may be formed from Lead-Tin (Pb-Sn) or Lead-Indium (Pb-In). Tin prevents oxidation and strengthens the bonding to the BLM.

The solder in the openings of the photoresist will straddle the gap **23** between the vias **22n**, merge, and eventually rise above the photoresist to become mushroom-shaped, as shown in **Figure 6 (d)**. The height of the photoresist and the pitch of the openings for the bumps must be well-controlled to produce a consistent solder height. Uniformity of solder height and alloy composition also depend on the current density distribution across the wafer and several parameters in the plating solution. Solder voiding can result from generation and entrapment of hydrogen gas and plating solution within the plated solder and must be prevented.

Excess portions of the upper layer **24b** and the lower layer **24a** which are not covered by solder **25** are removed by etching, as shown in **Figure 6 (e)**. Heating in an oven or a furnace will reflow the solder sitting on the segments **24n** of the BLM into a single bump **25** as shown in **Figure 6 (f)**. The melting temperature of the solder in the bump **25** on the chip depends on the types of metals selected and their relative concentrations. For example, a high Lead solder, such as 95 Pb/5 Sn by weight percent, reflows at about 300 to 360 degrees

C while a eutectic solder, such as 37 Pb/63 Sn, reflows at about 180 to 240 degrees C.

The bump **25** on the chip can be connected to a corresponding bump on a package or board. The bump on the package or board is formed from Tin (Sn) or solder with a relatively low melting temperature, such as 160 degrees C, so the bump **25** on the chip will not reflow during the chip attachment process.

Segmented BLM is compatible with other process flows used to form bumps for the I/Os. A few examples will be mentioned here. Electroless plating of Nickel (Ni) does not require a mask but requires that an intermediate layer, such as Zinc (Zn), be plated first on the Aluminum (Al) line. Conductive pillars surrounded by non-conductive dielectric may be used to electroplate the solder. Solder dams or solder stops may be used during reflow to limit the spreading of the bumps. The solder ball may be reflowed before the excess BLM is etched away to minimize undercutting of the BLM under the bump **25**. The upper layer **24b** and the lower layer **24a** of the BLM do not have to be etched sequentially. The BLM may be protected by photoresist during etch.

Segmented BLM is also compatible with other materials used for the bumps. A low alpha particle solder may be desirable to prevent soft errors. Alpha emission should be less than 0.02 count/hour/cm^2 in sensitive semiconductor devices such as memory chips. Environmental concerns require the elimination of metallic Lead (Pb) from solder by about the year 2004. A bump which is free of Lead (Pb) may be formed from Alternate Ball Metallurgy (ABM). ABM includes binary, ternary, and quaternary alloys formed from metals, such as Tin (Sn), Silver (Ag), Copper (Cu), Antimony (Sb), Indium (In), and Cadmium (Cd). An example is a Tin-Silver-Copper (Sn-Ag-Cu) ternary alloy with a melting point of about 215 degrees C. Other examples include a Tin-Copper (Sn-Cu) binary alloy or a Tin-Silver (Sn-Ag) binary alloy.

Solder itself may be eliminated by stencil printing the bumps from an Electrically Conductive Adhesive (ECA) or paste. ECAs include epoxy resin with a filler of conductive particles, such as Silver-filled epoxy. The electrical conductivity may be isotropic or anisotropic. ECAs are useful for thermally

sensitive devices s[redacted] a temperature of less than about [redacted] degrees C is needed to cure the adhesive by polymerizing the resin binder. ECAs have some disadvantages relative to solder bumps. Contact resistance of ECAs is about 25 micro-ohm which is higher than the 10 micro-ohm for solder. ECAs also have low thermal conductivities of about 1 to 3 W/mK so the device must operate at low power. However, electrically conductive polymers are being developed with thermal conductivities of about 60 W/mK which would be competitive with solder.

Various embodiments of a device with segmented BLM and the accompanying process to accomplish such a device have been described. The above embodiments refer to a bump overlying the segmented BLM. However, the present invention also contemplates a wire lead overlying a segmented bond pad. In that case, a wire bonder is modified to attach a wire lead to two or more segments of a bond pad so as to achieve similar beneficial reductions in incidence and severity of I/O failure.

Many embodiments and numerous details have been set forth above in order to provide a thorough understanding of the present invention. One skilled in the art will appreciate that many of the features in one embodiment are equally applicable to other embodiments. One skilled in the art will also appreciate the ability to make various equivalent substitutions for those specific materials, processes, dimensions, concentrations, etc. described herein. It is to be understood that the detailed description of the present invention should be taken as illustrative and not limiting, wherein the scope of the present invention should be determined by the claims that follow.

Thus, we have described a novel layout and process for a device with segmented BLM for the I/Os.